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PROPERTIES OF NIOBIUM

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THE EFFECT OF ALLOYING ON THE MECHANICAL PROPERTIES  
OF NIOBIUM

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Experimental studies on the effect of alloying in general and of alloys of niobium with B, La, Si, Cr, Re, Zr, Ir and other elements in particular on the mechanical properties of the alloy at high temperatures (up to 1300°C) are given, with tabulated and plotted data. Alloying of niobium in the region of solid solutions increases the tensile strength and decreases the plasticity at room temperature. The maximum strengthening effect is obtained in niobium alloys with Cr, Re, Zr and Ir. With increasing concentration of the solid solutions, Young's modulus and the high-temperature tensile strength increase further.

Author

In niobium-base alloys, as in several other metals, high strength can be obtained by establishing submicroscopic structural inhomogeneity. However, the strengthened state attained by heat treatment or thermomechanical treatment is metastable and persists for protracted times only if the motility of the atoms is low. At high temperatures, recrystallization and decomposition of the solid solutions take place, with segregation and coagulation of the phases, ultimately leading to loss of strength. Since these processes take place by diffusional displacement of atoms, the potential level of heat resistance is determined by

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\*\* Numbers in the margin indicate pagination in the original foreign text.

the strength of the interatomic bonds in the crystals of the phases of which the alloy is composed.

The main phase of an alloy is a solid solution. Increasing the forces of interatomic interaction in the base of the alloy - a solid solution - plays an important part in increasing the heat resistance, as has been shown by studies on alloys of iron, nickel and titanium (Bibl.1 - 4). The study of the effect of alloying on the forces of interatomic interaction is therefore of interest for the development of niobium alloys of complex composition.

The alloying elements studied were those forming continuous solid solutions with niobium at all temperatures (W, Mo, Ta) or solid solutions covering a very broad range of solubility (Ti, Re, Pd, Zr, Cr, Ir). In the latter case, the concentration of the alloying elements did not exceed their solubility limit in niobium.

The high-temperature strength of alloys depends to a considerable extent on the state of the grain boundaries, along which failure usually occurs. In this connection it may prove very useful in multi-element alloying to use alloying additions with horophil properties, and chemically active elements encouraging deoxidation.

We investigated B, Si, and La which are chemically active alloying additives with a low solubility in niobium. The solubility of lanthanum in niobium does not exceed 0.05 wt.% at room temperature (Bibl.5); there is no information on the solubility of boron and silicon, but we do know that these elements, which differ markedly from niobium in the size of their atoms, form narrow regions of interstitial solid solutions in the latter (Bibl.6 - 7).

The alloys were prepared in an arc furnace, in an argon atmosphere, first purified by passage through molten lithium. The charge consisted of commercial

niobium powder 98.7% pure, which was compressed into pellets and then vacuum-refined at a temperature close to the melting point (Bibl.8). Spectral and chemical analyses showed that after such refining the metal was free from lead and silicon impurities and that the carbon content had been decreased to 0.1%, 1741 the oxygen content to 0.001%, the iron to 0.04% and the hydrogen to 0.0004%. High-purity alloying elements were used.

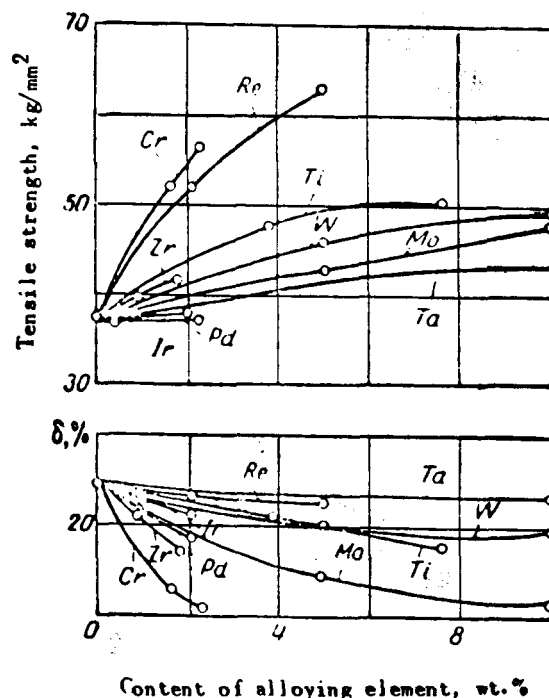


Fig.1 Tensile Strength and Plasticity of Niobium Alloys Plotted against Concentration of the Alloying Elements at Room Temperature ( $\delta$  = elongation)

The alloys were remelted at least five times to secure uniform distribution of the alloying elements in the ingots. These ingots were then rolled into rods on a vacuum rolling mill at 1100 - 1350°C (Bibl.9). To eliminate any possible residual work-hardening, the specimens prepared from the rod were subjected to a 40-hour vacuum anneal at 1400°C before testing their properties.

Our studies showed that the alloying of niobium in the region of solid

solutions causes changes in its properties corresponding to the general laws of alloying for alloys with any base. The increase in hardness (Bibl.10) and tensile strength and the decrease in plasticity, at equal concentrations, depend on the chemical nature of the alloying element, defined by its position in the periodic table and the ratio of the atomic diameters. Figure 1 indicates that the greatest increase in strength of niobium alloys at room temperature is produced by Cr, Re, and Ti whose atomic diameters differ greatly from that of niobium. Relatively little strengthening effect on niobium is manifested by W, Mo, and Ta whose physicochemical properties resemble those of niobium and whose atomic diameters differ little from that of niobium. It should be noted that Mo, W, and Ta lower the plasticity of niobium only slightly, while Cr and Zr, on the other hand, lower it sharply.

Interatomic interaction was studied in solid solutions of niobium by measuring the modulus of elasticity and calculating its temperature coefficient. The high-temperature measurements, including the tensile-strength tests, were made in vacuum under a residual pressure of not over  $1 \times 10^{-5}$  mm Hg.

The modulus of elasticity was determined by the resonance method, from the flexural vibrations of cylindrical specimens. The specimens were heated in an unlined furnace. The modulus of elasticity was calculated by means of the formula

$$E = 1.6388 \cdot 10^{-8} \left( \frac{l}{D} \right)^4 \frac{G}{l} f^2,$$

where  $l$  is the length of the specimen, in cm;  $f$  is the natural frequency of flexural vibrations of the specimen, in cps;  $D$  is the diameter of the specimen; and  $G$  the weight, in gm.

The specimens were 75 mm long and 7 mm in diameter; the frequency of the vibrations was measured with an accuracy to within 0.2%.

The temperature coefficient was calculated from the Köster-Frantsevich

formula (Bibl.11, 12):

$$\theta = \frac{1.6818 \cdot 10^6 \sqrt{E}}{\bar{A}^{\frac{1}{3}} \cdot d^{\frac{1}{6}}},$$

where E is the modulus of elasticity of the alloy, d its specific gravity, 742 and  $\bar{A}$  the mean atomic weight.

An investigation of the elastic constants showed that, at room temperature, the modulus of elasticity of niobium is 10,800 kg/mm<sup>2</sup>, which is in satisfactory agreement with data given elsewhere (Bibl.13 - 15). Alloying of niobium with

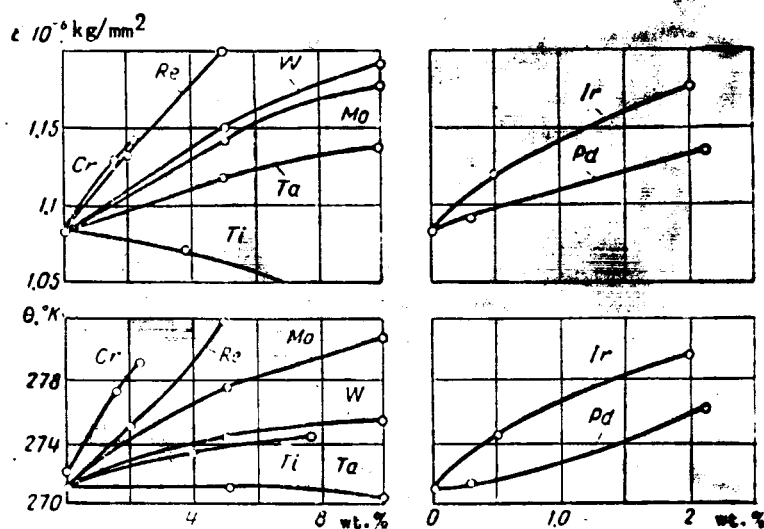


Fig.2 Modulus of Elasticity E and Temperature Coefficient  $\theta$  as a Function of the Alloy Composition

chromium, rhenium, tungsten, molybdenum, tantalum, iridium, or palladium increases the modulus of elasticity at room temperature (Fig.2). Titanium somewhat decreases it. Alloying elements act similarly on the temperature characteristic. The increase in these values is greater, the higher the concentration of the alloying element. The temperature characteristic for pure niobium found by us is lower than that found by Frantsevich (Bibl.12), probably owing to a difference in purity of the metals used. 743

# EFFECT OF TEMPERATURE ON THE MODULUS OF ELASTICITY OF NIOBIUM-BASE ALLOYS

Alloy Composition wt. %	Modulus of Elasticity, $E \cdot 10^{-6}$ kg/cm <sup>2</sup> , at Temperatures (°C)						
	20	300	500	700	900	1100	1300
Nb	1.083	1.081	1.082	1.085	1.091	1.097	1.108
Nb+5.0 Mo	1.144	1.135	1.136	1.149	1.172	1.186	1.213
Nb+10.0 Mo	1.189	1.175	1.191	1.210	1.232	1.233	1.233
Nb+5.0 Ta	1.118	1.117	1.118	1.124	1.145	1.152	1.152
Nb+10.0 Ta	1.139	1.137	1.138	1.145	1.155	1.156	1.156
Nb+5.0 W	1.151	1.145	1.143	1.153	1.168	1.175	1.175
Nb+10.0 W	1.192	1.185	1.196	1.201	1.212	1.225	1.225
Nb+2.0 Re	1.135	1.128	1.126	1.127	1.129	1.134	1.136
Nb+5.0 Re	1.216	1.211	1.210	1.213	1.215	1.223	1.225
Nb+1.55 Cr	1.128	1.130	1.135	1.135	1.136	1.130	1.134
Nb+2.3 Cr	1.142	1.130	1.140	1.142	1.141	1.138	1.138
Nb+3.83 Ti	1.072	1.073	1.074	1.075	1.076	1.076	1.076
Nb+7.6 Ti	1.044	1.043	1.044	1.042	1.042	1.037	1.032
Nb+0.5 Ir	1.119	1.117	1.101	1.111	1.118	1.116	1.112
Nb+2.0 Ir	1.174	1.165	1.165	1.172	1.175	1.180	1.180
Nb+0.3 Pd	1.094	1.095	1.102	1.114	1.116	1.113	1.110
Nb+2.17 Pd	1.136	1.139	1.142	1.141	1.143	1.137	1.130
Nb+0.4 La	1.096	1.095	1.096	1.103	1.110	1.120	1.123
Nb+0.55 La	1.072	1.071	1.074	1.082	1.084	1.090	1.096
Nb+0.17B	1.114	1.112	1.118	1.135	1.151	1.159	1.162
Nb+0.23B	1.150	1.150	1.172	1.184	1.198	1.210	1.214
Nb+0.32 Si	1.101	1.101	1.164	1.120	1.129	1.148	1.154
Nb+0.5 Si	1.121	1.121	1.124	1.144	1.162	1.174	1.176

On increasing the temperature to 1300°C, the modulus of elasticity, both for pure niobium and for most of its alloys, will increase slightly (see Table).

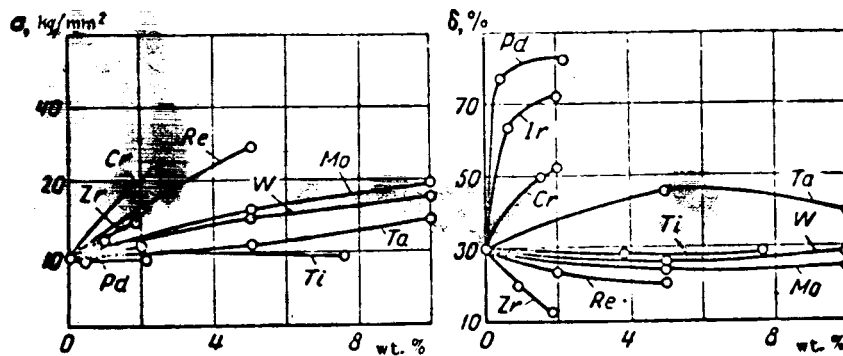


Fig.3 Mechanical Properties of Alloys as a Function of the Composition, at a Temperature of 1100°C

Figure 3 shows that alloying of niobium with chromium, rhenium, zirconium, molybdenum, tungsten, iridium, and tantalum will increase the tensile strength

of the alloys at high temperatures as well, whereas Ti and Pd slightly increase the strength at 1100°C. It is characteristic that Cr, Ir, and Pd at low concentrations should increase the elongation at 1100°C. The data on high-temperature tensile strength are in satisfactory agreement with Begley (Bibl.16).

The results show that alloying elements such as Cr, Re, Mo, W, and Zr are very useful for niobium alloys, all the more so since most of them, when they enter into solid solution, increase the recrystallization temperature (Bibl. 17) and thus help to increase the creep resistance, while Cr and Mo, in addition to this, appreciably enhance the heat resistance (Bibl.18 -21).

Of course, the strength of the interatomic bond in solid solutions does not completely determine the heat resistance of niobium-base alloys, a statement that holds true also for alloys with any other base. This would require factors to retard the propagation of plastic deformation (formation of heat-resistant chemical compounds and their rational distribution within the alloy, strengthening of the grain boundaries, etc.), which can be attained in multi-element alloying. However, the strengthening of the interatomic bond in the crystal lattice of solid solutions of niobium, confirmed by the increase in the modulus of elasticity and in the temperature coefficient, as well as the decrease in the coefficients of thermal expansion (Bibl.22), establish the prerequisites for increasing the temperature level of heat resistance of these alloys.

Figure 4 shows the dependence of the physico-mechanical properties of heterogeneous alloys of niobium with boron, silicon, and lanthanum on the content of these elements. The greatest increase in the modulus of elasticity and tensile strength at room temperature, at the investigated concentrations, is produced by boron, but the plasticity declines appreciably.



The greatest increase in strength at 1100°C is likewise observed in 744 boron alloys, evidently owing to the formation of refractory borides. Silicon imparts only a slight increase in strength at room temperature and at 1100°C, accompanied by an appreciable decrease in plasticity.

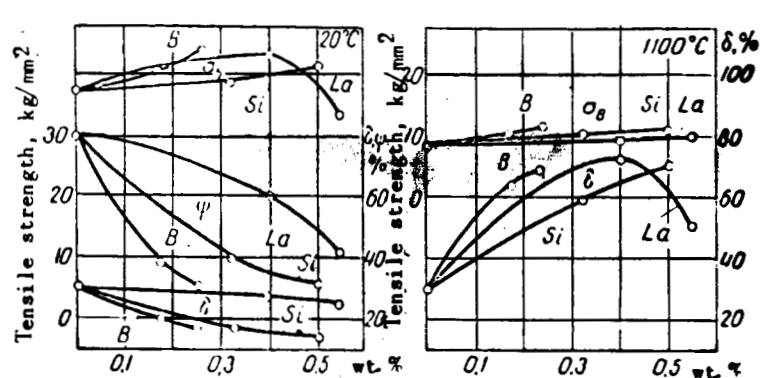


Fig.4 Mechanical Properties of Alloys of Niobium with Boron, Lanthanum, and Silicon as a Function of the Content of these Metals ( $\delta$  = elongation;  $\psi$  = reduction in area)

Lanthanum increases the tensile strength and modulus of elasticity at room temperature only up to concentrations of about 0.3 wt.%; with a further increase in concentration the strength declines, apparently owing to the poorer mechanical properties of the second phase.

#### CONCLUSIONS

1. The alloying of niobium in the region of solid solutions increases the tensile strength and decreases the plasticity of the alloys at room temperature, according to the general laws of strengthening of solid solutions; the most effective strengthening effect on niobium is produced by Cr, Re, Zr, and Ir which differ significantly from niobium in atomic diameter.

2. With increasing concentration of the solid solutions of niobium with

tantalum, tungsten, rhenium, molybdenum, and iridium, the modulus of elasticity at room temperature and at high temperatures increases together with the temperature coefficient and the high-temperature tensile strength, while the coefficient of thermal expansion decreases, indicating an increase in the forces of interatomic action.

3. In niobium alloys of heterogeneous structure, the physico-mechanical properties are determined by the strengthening of the solid solution and by the properties of the second phase. Among niobium alloys with boron, lanthanum, and silicon, the greatest strengthening is caused by boron.

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